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PHOSPHORUS CONTROL AND NITRIFICATION PROCESSES FOR MUNICIPAL WASTEWATER

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16. ABSTRACT

The projected needs for constructing new facilities, between the year 1982 and the year 2000, for control of nutrients in municipal effluents is discussed.

Example technologies for control of phosphorus and nitrogen to defined effluent residuals are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Introduction

In the United States there are no uniform Federal standards for the regulation of nitrogen or phosphorus compounds in discharges from municipal treatment facilities. Any such restrictions which do exist are based on the effects of these type materials on a specific drainage area, individual state, or local municipal receiving water situation.

An example of regulatory control by drainage area would be the Great Lakes Water Quality Agreement, under the terms of the 1909 Boundary Waters Treaty between the United States and Canada. The five lakes that are collectively called the Great Lakes, are the largest contiguous freshwater system in the world. Due to the long hydraulic detention time of water in the lakes and their surface to volume configuration; eutrophication due to phosphorus is a major environmental concern. Under terms of the Agreement, both Nations enforce a limitation of 1 mg/L total phosphorus for any discharge to the drainage area that is 3,785 m^3/d (1 mgd) or greater. There are 390 treatment facilities that are impacted by this limitation. Since the initial Agreement in 1966, to the year 1981, the input of total phosphorus into the Great Lakes has been reduced from 5,400 metric tons per year to 1,600 metric

tons per year.(1) Over this time period, the two governments had invested 7.5 billion dollars in treatment plant construction in this region.

An example of restrictions on an individual state bases is the Wilson-Grizzle Act under Chapter 17-3.04 of the State of Florida's Administrative Code. Due to the shallow groundwater table, high actinic radiation levels, warm climate, and water related tourism, the Act requires stringent treatment for wastewater. Both nitrogen and phosphorus have potential for causing eutrophication in waters of Florida. Any discharge to a lake, impoundment, bay, or estuary must not exceed effluent residuals of 8 mg/L biochemical oxygen demand (BOD_5), 8 mg/L suspended solids (SS), 5 mg/L total nitrogen (TN), and 1 mg/L total phosphorus (TP).(2)

A local municipal situation that exemplifies the need to restrict ammonium nitrogen discharge would be the City of Des Moines, Iowa. Because of deteriorating infrastructure, the City has decided to abandon 12 separate outlying municipal facilities and 38 semi-private facilities, and collect and treat the combined wastewaters at the existing major Des Moines trickling filter facility. Since the previous multiple effluent flows will now be discharged as a single regional point source of 380×10^3 m^3/day (100 mgd), ammonium nitrogen is the most serious environmental concern. Nitrification must be accomplished during the critical summer months to attain receiving water quality standards for dissolved oxygen. To accomplish this goal, major work on conveyance systems, upstream flow equalization, addition of second stage activated sludge to the existing trickling filters, and provision for adequate final clarification capacity, must be done. The cost of these upgrading activities is estimated at $207,000,000 (U.S.D).(3)

Figure 1 is an outline map of the United States of America in order to place these three case examples in geographical perspective. The City of Cincinnati is noted as a reference point. Other examples could be cited but each would show that site specific considerations have to be evaluated to establish the need for nutrient control technology. Treatment for control of nutrients has a high enough incremental cost above achieving Federal secondary standards that to avoid unnecessary economic burden, there is not likely to be any uniform Federal standards for nutrients in the near future.

Treatment Capacity of the United States and Territories

Every two years the U.S. EPA must report to Congress regarding present and future capacity for treatment of wastewater. These reports are titled, Needs Surveys, and the last issue was dated 1982, which projects capacity needs to the Year 2000.(4) Figure 2 shows the number of facilities in different design size ranges and the percent of the total wastewater that are treated by the facilities in these ranges for the Year 1982 compared with the Year 2000.

During this time interval, 5,010 facilities in the two smaller design ranges need to be constructed. Only 586 facilities in the larger three design ranges need to be constructed. Currently the 12,151 facilities in the design range of 3.8×10^3 m^3/d (1 mgd) or less treat only 8.5 percent of the total wastewater flow. The much smaller number of 3,280 facilities in the larger design ranges treat 91.5 percent of the wastewater. This situation will not change a great deal by the Year 2000.

Figure 1. Exemplary cases of effluent restriction for geographical areas.

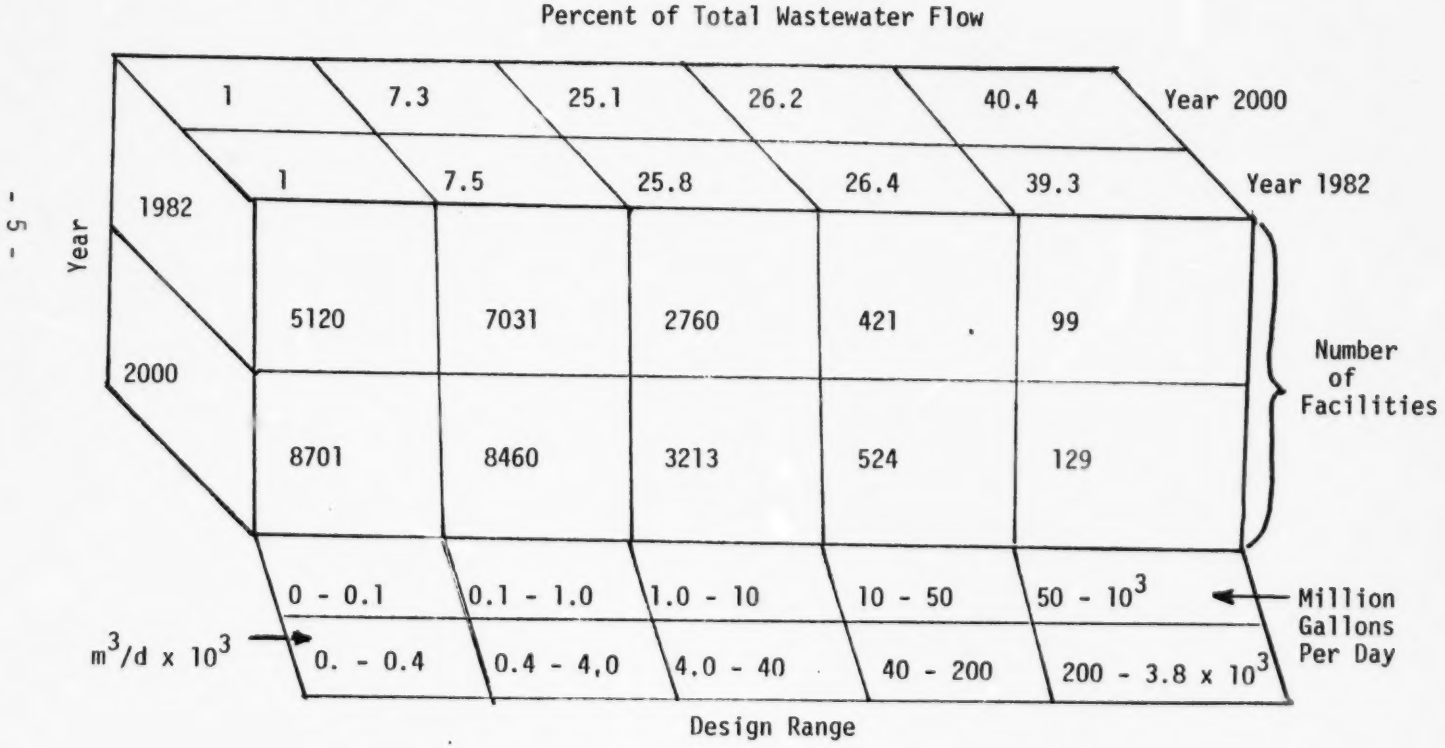

Figure 2. 1982 Needs Survey of United States and Territories, Treatment Capacity.

Table 1 shows the efficiency of secondary treatment for the removal of BOD_5 and SS on a National bases, for the Year 1982 and projected to the Year 2000. While there will be increased flow, BOD_5, and SS loadings, during this time period the overall percent removals will not increase greatly. This is due to the fact that for the last twenty years, most Federally-funded facilities have been designed to achieve minimum Federal secondary treatment standards.

The types of processes constructed to achieve secondary treatment are given in Table 2, with projected processes for the Year 2000. Due to simplicity of operation, low capital and operational costs, lagoon technology is a popular treatment option. The number of trickling filter facilities is expected to decline due largely to obsolescence. The number of activated sludge, land treatment systems, oxidation ditches and rotating biological disc processes will all show increases in number of installed processes. The category called Other includes primary plants, Imhoff tanks and physical-chemical processes. These will mostly be replaced by activated sludge systems. The total number of processes given exceeds the total number of facilities because some facilities have more than one process; for example, a two-stage trickling filter-activated sludge process.

Classes of Treatment Technology

Generally, designs for municipal facilities can be grouped into three classes of treatment technology required to achieve defined effluent qualities, as shown in Table 3. Secondary treatment, to achieve 25-30 mg/L BOD_5 and SS, is the uniform federal standard applied across the Nation. Designs

TABLE 1. NATIONAL SECONDARY TREATMENT EFFICIENCY

Year 1982		Year 2000
	Wastewater Flow:	
99×10^6 m^3/day (Actual)		160×10^6 m^3/day (Projected)
26.1×10^3 mgd		42.7×10^3 mgd
	BOD_5:	
	Metric Tons/day	
20.5×10^3	Influent	35.3×10^3
4.1×10^3	Effluent	3.9×10^3
80%	Percent Removal	89%
	Suspended Solids:	
	Metric Tons/day	
23.3×10^3	Influent	37.3×10^3
4.0×10^3	Effluent	4.1×10^3
83%	Percent Removal	89%

TABLE 2. NUMBER AND TYPE OF TREATMENT PROCESSES, UNITED STATES AND TERRITORIES

Year 1982		Year 2000
15,431	Total Number of Facilities	21,027
	Type and Number of Processes:	
7,010	Lagoons	10,993
5,664	Activated Sludge	8,033
2,639	Trickling Filter	1,865
806	Land Treatment	1,438
631	Oxidation Ditch	1,288
257	Rotating Disc	716
862	Other	291
17,869	Total Processes	24,624

TABLE 3. EFFLUENT QUALITY IN RELATION TO TYPE OF TREATMENT TECHNOLOGY

Type of Treatment Technology	Effluent Quality (All values in mg/L)
Secondary	BOD_5, 25 - 30 SS, 25 - 30
Advanced Secondary	BOD_5, 9 - 25 SS, 9 - 25 and/or TP, 1 NH_4-N, 0 - 5
Advanced Waste Treatment	BOD_5, 2 - 9 SS, 2 - 9 TN, 2 - 10

for secondary treatment receive routine engineering review for adherence to general guidelines, and the facility is eligible for Federal funding.

Advanced Secondary Treatment has more stringent effluent limitations with regard to BOD_5 and SS. Nitrification may be necessary for control of dissolved oxygen in a site specific instance. Or, phosphorus removal may be necessary to protect a local lake. In these cases, the design is more rigorously reviewed both from an administrative and engineering viewpoint. The EPA Regional Administrator must review the design and verify the need for efficiencies greater than secondary treatment before Federal funds can be utilized. An exception to the review would be phosphorus removal at any facility tributary to the Great Lakes, due to the treaty obligation with Canada.

Facility designs for Advanced Waste Treatment for stringent effluent residuals of BOD_5, SS, or total nitrogen receive technical review at the EPA Washington, DC headquarters. This review also considers the analysis of receiving water quality that lead to the decision to impose strict residuals. Before funding of the Facility, the EPA Administrator must approve the need for this level of technology at that specific site.

Technologies Applied for Phosphorus Control

The great majority of the municipal treatment plants that are required to control phosphorus must achieve an effluent residual total phosphorus of

of 1 mg/L. Table 4 lists the processes commonly employed to achieve this residual. Experience since 1966 has shown that provision for addition of metallic salts, such as ferric chloride or aluminum sulfate, to conventional secondary treatment processes is an effective technology.(5)

In the last several years, a large interest in biological processes for controlling the phosphorus in municipal effluents has occurred. These processes operate by managing the environmental cycles imposed in a bioreactor. The attractive feature of the biological approach is the reduction in the amount of inert sludge generated in the metallic salt addition approach. However, due to inherent biological variability, it is recommended that these biological processes also provide stand-by chemical addition for polish dosing to insure effluent residual are consistently at 1 mg/L total phosphorus.(6)

In several local situations, a total phosphorus residual of 0.5 mg/L is specified. Table 5 shows that this requirement can be achieved by increasing the molar ratio of metallic salt to phosphorus in conventional secondary processes; and instituting tertiary media filtration to control particulate matter. For a residual near 0.3 mg/L, close control of the pH value is necessary to insure maximum insolubility of the metal/phosphorus precipitates.

In a very few cases, an effluent total phosphorus residual of 0.2 mg/l, or less, has been required. This requirement necessitates provision for multi-stage advanced waste treatment (Table 6). First, a biological process must be employed to remove organics and biologically convert the polyphosphates present in raw waste into orthophosphates. Then the biological effluent

TABLE 4.

TECHNOLOGIES FOR PHOSPHORUS CONTROL

I. TOTAL PHOSPHORUS RESIDUAL, 1 mg/l

METAL SALT ADDITION TO CONVENTIONAL PROCESSES:

MOLAR RATIO — M^{+3}/P, 1.2/1

ACTIVATED SLUDGE
TRICKLING FILTER
ROTATING BIOLOGICAL CONTACTOR

BIOLOGICAL PHOSPHORUS UPTAKE:

PHOSTRIP
ANAEROBIC/OXIC*
BARDENPHO*

*REQUIRE SUPPLEMENTAL METAL SALT ADDITION

TABLE 5.

TECHNOLOGIES FOR PHOSPHORUS CONTROL

II. TOTAL PHOSPHORUS RESIDUAL, 0.5 to 0.3 mg/l

SAME PROCESSES LISTED IN I, PLUS:

MOLAR RATIO M^{+3}/P, 1.5/1

CONTROL OF pH

TERTIARY MEDIA FILTRATION

TABLE 6.

TECHNOLOGIES FOR PHOSPHORUS CONTROL

III. TOTAL PHOSPHORUS RESIDUAL, 0.2 mg/l or less

ATTACHED OR SUSPENDED GROWTH PROCESS FOR CARBONACEOUS REMOVAL AND HYDROLYSIS OF POLYPHOSPHATES TO ORTHOPHOSPHATES, FOLLOWED BY:

TWO-STAGE LIME PRECIPITATION
TERTIARY MEDIA FILTRATION

must be treated with two-stage lime for insolubilization of phosphorus. Finally, the lime treated effluent must be filtered to remove any suspended solids. The capital and operating costs for this type technology are so intensive and energy demanding that a great deal of justification is needed before implementing this technology.(7)

Technologies Applied for Nitrogen

Nitrogen in its various chemical forms can have substantial environmental impacts on receiving waters.(8) The most prevalent of these is the reduction in dissolved oxygen caused by the in situ microbiological oxidation of ammonium. Therefore, in the United States, the provision for nitrification at municipal facilities is of paramount importance. Process for removal of total nitrogen is of very minor concern and is instituted at only a few sites.

Generally effluent requirements for nitrification occur in two classes; a moderate requirement of 3 to 5 mg/L ammonium nitrogen, or a more stringent 1 mg/L residual. Table 7 shows that the moderate residual can be achieved with a variety of either attached or suspended growth processes. It should be noted that the key design consideration for all nitrification processes is provision for environmental conditions for the growth of fastidious micro-organism that oxidize ammonium. The microbial cellular mass that arises from biological treatment of wastewater must be managed so that the heterotropic organisms do not over-grow the chemotrophic nitrifying organisms. In suspended growth systems this is accomplished by managing the mixed liquor suspended solids wastage rate so the solids retention time (SRT) allows

TABLE 7.

TECHNOLOGIES FOR NITRIFICATION

I. RESIDUAL NH_4-N, 3-5 mg/l

ATTACHED GROWTH SYSTEMS:

ROCK MEDIA FILTER — 6 ft (1.8 m) depth
10 lbs BOD_5/1,000 ft^3/day (0.16 kg/m^3/day)

PLASTIC MEDIA FILTER — 21 ft (6.3 m) depth
22 lbs BOD_5/1,000 ft^3/day (0.35 kg/m^3/day)

ROTATING BIOLOGICAL CONTACTOR
0.75 gallon/ft^2/day (30 l/m^2/day)

SUSPENDED GROWTH SYSTEMS:

HRT 6-8 HOURS
SRT 5-7 DAYS

nitrifier reproduction at the design temperature coefficient. For attached growth systems, the proper film thickness to allow attachment of nitrifying organisms is controlled by reduced volumetric and hydraulic loadings, compared with carbonaceous removal design.

The stringent 1 mg/L ammonium nitrogen limitation requires very rigorous design. If nitrification is a requirement in winter, the size of suspended growth systems becomes very large and long SRT is paramount. Due to this long SRT and consequent increased mixed liquor solids, clarifier capacity is an interrelated design constraint (Table 8).

Most of these design considerations can best be solved by employing two-stage treatment for stringent ammonium residual requirements.(9) In this technology, carbonaceous oxidation and ammonium oxidation are carried out in sequential bioreactors. Various combinations of attached growth and suspended growth reactors have been employed.(10)

To consistently achieve a 1 mg/L ammonium nitrogen residual, the design will also have to consider short-circuiting. A plug-flow reactor would be prudent. Additional features would be control of high strength internal recycle flows, such as digester supernatant; which can contain 1,000 mg/L of ammonium nitrogen.(11) Hydrogen ion control is important since the nitrifying organisms have optimum activity for nitrification in the pH range of 6.5 to 8.5. Severe depression of the pH value can occur in municipal waters with low alkalinities. For each part of

TABLE 8.

TECHNOLOGIES FOR NITRIFICATION

II. RESIDUAL NH_4-N, 1 mg/l

SUSPENDED GROWTH SYSTEMS:

HRT 18-24 HOURS

SRT 10-15 DAYS

TWO-STAGE BIOLOGICAL SYSTEMS:

VARIOUS COMBINATIONS OF ATTACHED AND SUSPENDED GROWTH PROCESSES

1ST STAGE, HIGH RATE CARBONACEOUS

2ND STAGE, NITRIFICATION

ammonium nitrogen oxidized to nitrate, 7.1 parts of alkalinity, expressed as calcium carbonate, will be destroyed. Residual alkalinity after nitrification should be maintained at about 50 mg/L.

Design and operational details for many nitrogen control options are provided in a design manual prepared by EPA.(12)

Operating experience has shown that efficiency of municipal treatment should be measured with a modification of the standard BOD_5 test.(13) This new test is called carbonaceous biological oxygen demand (CBOD) and employs the chemical 2-chloro-6(trimethyl)pyridine (TCMP) to inhibit nitrification during incubation of the sample.(14) Figure 3 depicts the action of TCMP on the sequential biological oxidation of ammonium. Use of CBOD is considered very important to accurately determine compliance with effluent standards. In the standard BOD_5 test, the extent of nitrification is erratic and the result is a doubtful measure of treatment efficiency. Since the biological oxidation of 1 mg of ammonium nitrogen consumes 4.56 mg of oxygen, only a few mg/L of ammonium nitrogen in an effluent could drastically effect the test results. In Table 9, the theoretical oxygen demand for both BOD_5 and CBOD for two types of effluent are given. Nitrification during the incubation can seriously impact compliance attainment. This is particularly true with Advanced Secondary Treatment facilities because the nitrifier population would not be stable during winter time operation if the designer sized the aeration system for full nitrification only in the summer. During winter, the effluent would be partially nitrified and the nitrifier organisms in the effluent would seed the standard BOD_5 test and oxidation of ammonium would be rapid.

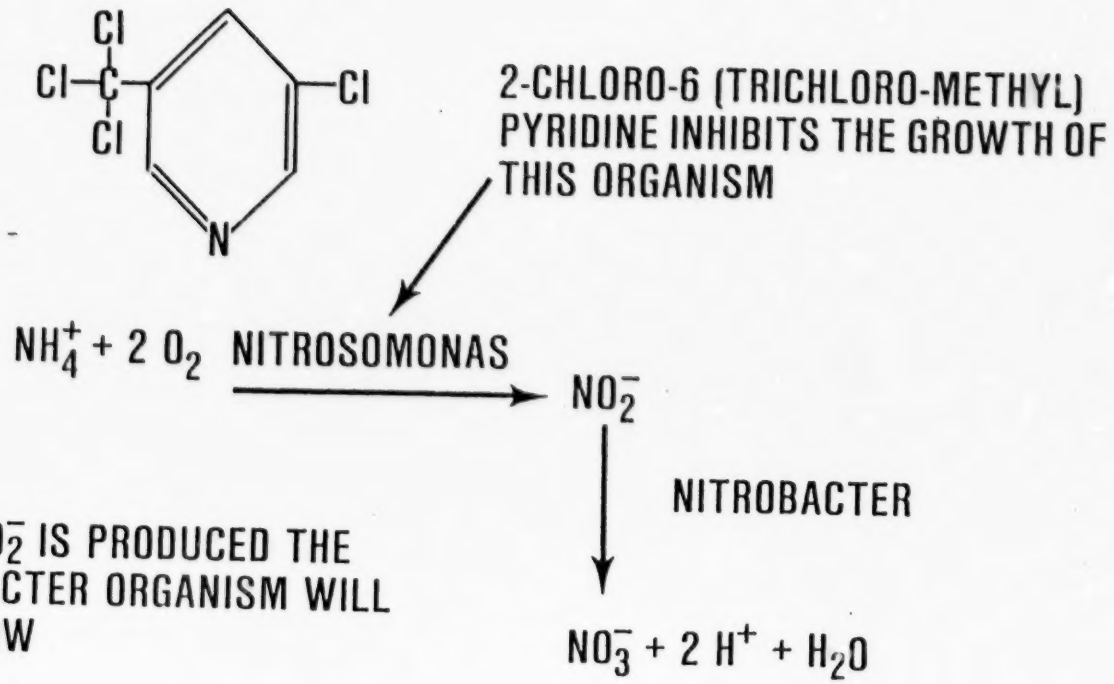

Figure 3. "TCMP" (10 mg/L) added to BOD dilution water.

TABLE 9. EFFLUENT COMPLIANCE

SECONDARY TREATMENT 30 mg/l BOD_5	ADVANCED SECONDARY TREATMENT 20 mg/l BOD_5, 1 mg/l NH_4^+-N (Summer)	
	RESULT, mg/l	
	$CBOD_5$	NITRIFICATION OCCURS BOD_5
SECONDARY EFFLUENT:		
25 mg/l ORGANIC MATTER	x 1 = 25	x 1 = 25
15 mg/l NH_4^+-N	x 0 = 0	x 4.56 = 69
	25	94
AST EFFLUENT (SUMMER):		
15 mg/l ORGANIC MATTER	x 1 = 15	x 1 = 15
1 mg/l NH_4^+-N	x 0 = 0	x 4.56 = 5
	15	20
AST EFFLUENT (WINTER):		
15 mg/l ORGANIC MATTER	x 1 = 15	x 1 = 15
5 mg/l NH_4^+-N	x 0 = 0	x 4.56 = 23
	15	38

Implementation of Nutrient Control in the United States

Table 10 lists the number, daily flow, and percent of total United States daily flow, of facilities operated for nutrient control for the Year 1982, and projected to the Year 2000.

During this time interval, the number of phosphorus control facilities will increase by a factor of 2. The number of nitrification treatment plants will quadruple and 27 percent of the Nation's wastewater flow will be nitrified. This emphasizes the importance of nitrification in municipal control technology. Contrasted to this is the fact that currently only 47 facilities are required to remove nitrogen. There will be only a small increase in the number of new nitrogen removal facilities and only 1.8 percent of the total flow will be treated by this type technology.

Total Treatment Capability of United States and Territories

Figure 4 shows the design flow, number of facilities in technology categories, and the percent of total flow treated by each technology between the Years 1982 and 2000.

Facilities that do not discharge an effluent will increase from 1,600 to 2,736 in number. These are evaporation lagoons, infiltration systems, spray irrigation, or ground water recharge processes.

TABLE 10. PHOSPHORUS AND NITROGEN CONTROL CAPABILITY OF THE UNITED STATES

Year 1982		Year 2000
	Phosphorus Removal	
586	Number of Facilities	1,233
(3,690 mgd) 14×10^6 m^3/d	Flow Treated	32×10^6 m^3/d (8,454 mgd)
14%	Percent of Total Flow	20%
	Nitrification	
686	Number of Facilities	2,880
(3,435 mgd) 13×10^6 m^3/d	Flow Treated	42×10^6 m^3/d (11,096 mgd)
13%	Percent of Total Flow	27%
	Nitrogen Removal	
47	Number of Facilities	104
(237 mgd) 0.9×10^6 m^3/d	Flow Treated	3×10^6 m^3/d (793 mgd)
0.9%	Percent of Total Flow	1.8%

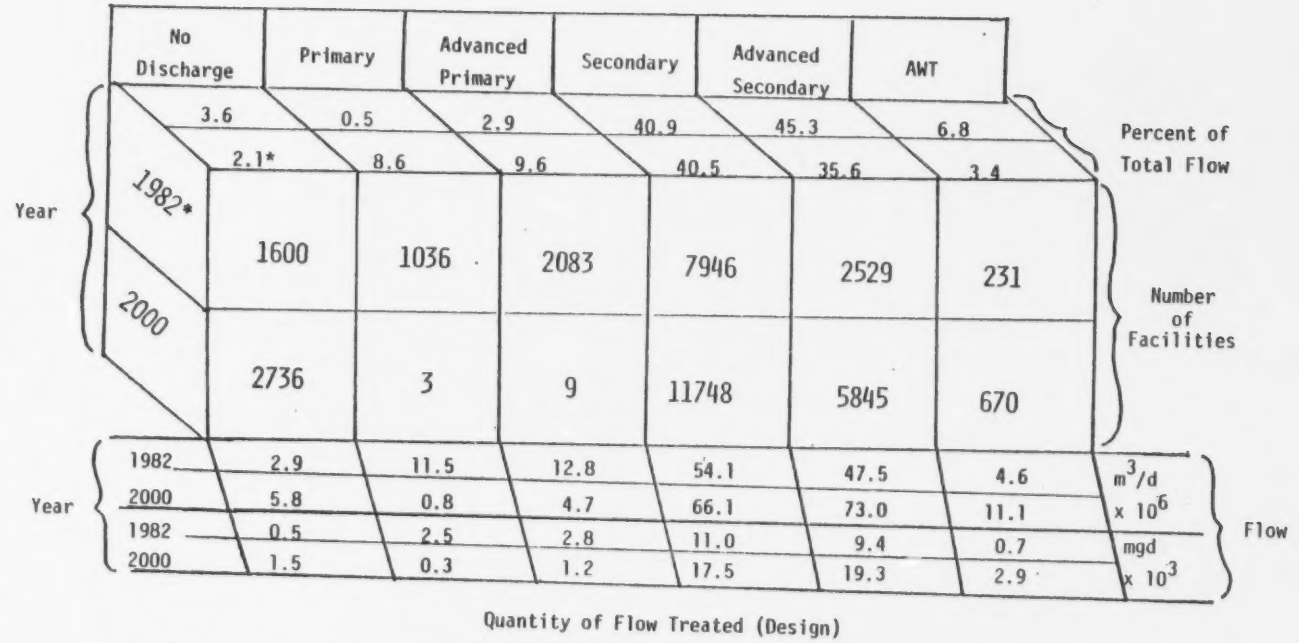

Figure 4. Total treatment capability of the United States, Year 1982 to 2000.

The number of primary and advanced primary treatment operations will decrease from the current 3,119 facilities to only 12 plants by the Year 2000. Most of these will be upgraded to secondary technology as can be noted by the large increase in the number of these type facilities, 3,802, over this time period.

Advanced Secondary Treatment will be implemented at a rapid pace, with a growth of 3,316 facilities providing this technology. By the Year 2000, 73×10^6 m^3/d (19×10^3 mgd) will be treated by this technology, which represents 45% of the total daily wastewater flow.

Very little increase in Advanced Waste Treatment is expected. Only 670 facilities will be in operation by the Year 2000, and only 6.8 percent of the total daily flow will require this level of technology.

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